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DEVELOPMENT OF LIGHTWEIGHT PORTABLE LOUDSPEAKER.(U)

JUL 79 R B JACKSON

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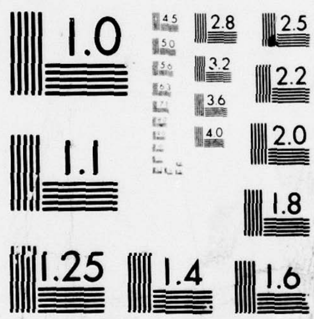

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RESEARCH AND DEVELOPMENT TECHNICAL REPORT
CORADCOM- 77-0187-F

DEVELOPMENT OF LIGHTWEIGHT PORTABLE LOUDSPEAKER

Robert B. Jackson
ELECTRO-VOICE INC
600 Cecil Street
Buchanan, MI 49107

July 1979

Final Report for Period Sep 1977 - Jun 1979

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number):

This document covers the technical details of work performed to develop a lightweight portable loudspeaker to be worn on the epaulet or pocket of the person carrying a backpack radio. The amplifier contained in the case is powered by the X-mode output of the PRC-70 and other field radios. The loudspeaker supplies approximately 85 dB SPL at one meter and is able to withstand severe environment.

410529

FINAL TECHNICAL REPORT

DEVELOPMENT OF

LIGHTWEIGHT PORTABLE LOUDSPEAKER

CONTRACT NO. DAAB07-77-C-0187

LINE ITEM 0002

JUNE 1979

New loudspeaker weighs less than one pound and can be worn by a person. It is powered by the X-mode connector of radio sets such as the PRC-70 and supplies approximately 85 dB SPL at one meter.

By
R. B. Jackson

Submitted to

US Army Communications Research
and Development Command (CORADCOM)
DRDCO-COM-RN-4
Fort Monmouth, New Jersey 07703

Electro-Voice, Inc.
Military Engineering Department
600 Cecil Street
Buchanan, Michigan 49107

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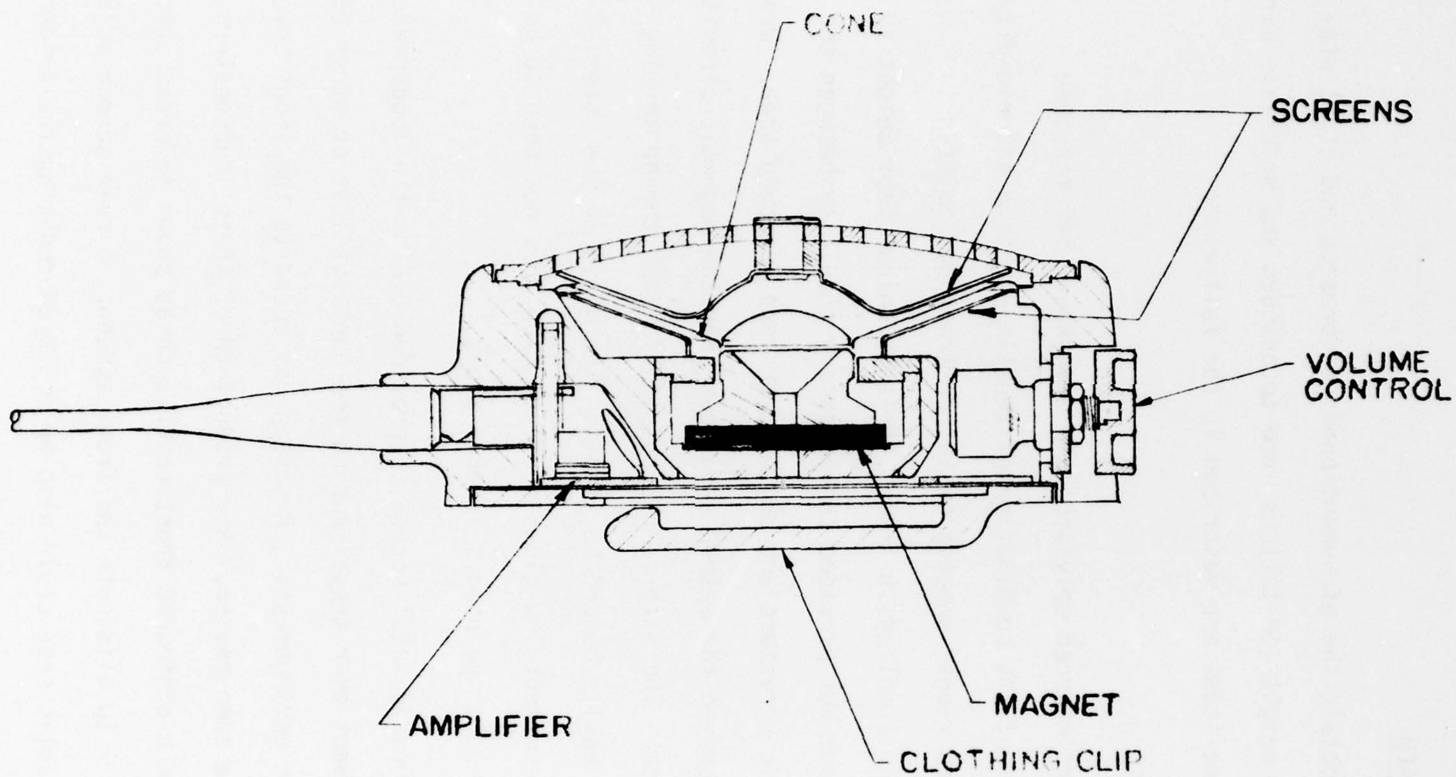
ILLUSTRATIONS

PURPOSE

The purpose of the development effort described herein was to provide a loudspeaker for the PRC/70 and other backpack radios. These radios were designed to deliver audio power to headphones and to handset receivers, but do not provide sufficient power to operate a loudspeaker. The loudspeaker desired for the application was to be of moving coil design, light in weight, at less than a pound, and small in size. The original size was to be 3-1/2 by 3-1/2 by 1 inches. This was later changed to a round configuration by CORADCOM Engineering. It was required to use the U-316/U connector to mate with the X-mode output of the radios.

The performance specified for the loudspeaker required an acoustic output of 85 dB SPL between 500 and 2000 Hertz at a distance of one meter. The end result is a loudspeaker which very nearly meets these performance specifications, as shown in Figure 6.

Figure 1 shows a cutaway view of the Lightweight Portable Loudspeaker.



CROSS-SECTION OF LOUDSPEAKER

FIG 1

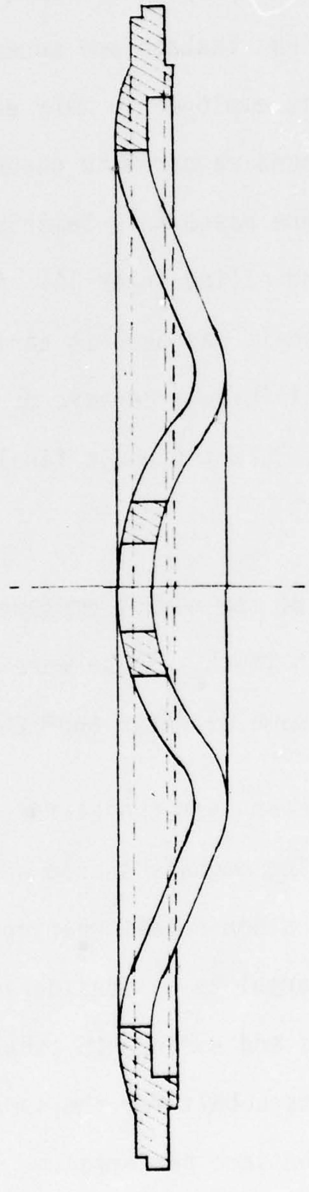
DESIGN APPROACH

In order to obtain the aforementioned performance and still stay within the size and weight limitations, new techniques and materials were employed. These items are described in the following:

The Case

Glass reinforced polycarbonate was chosen for the case because of its combination of tensile strength and rigidity. The traditional speaker basket or frame was omitted in favor of a molded-in frame. This technique kept weight to a minimum but provided the necessary stability between the magnetic structure and the speaker cone surround area. Drop tests proved the method used does keep the magnetic circuit in place. The material is compatible with thread forming screws and is easily bonded to itself. The glass in the material gives it a permanent low-gloss surface which does not need to be roughened or painted to reduce gloss.

A perforated metal screen is provided behind the loudspeaker cone to prevent over travel during the Gunblast Test or other percussive environments. A screen was added to the front cover for the same reason. Any production of these loudspeakers should utilize a contoured front cover such as shown in cross section in Figure 2 to eliminate the front screen. A rear screen molded into the plastic case could also be employed reducing the number of parts required.



CROSS - SECTION OF PROPOSED COVER

FIG 2

The Magnetic Structure

The magnetic structure employed is a cup, faceplate, polepiece design which has minimal leakage and superior structural rigidity. This type structure is employed in many earphone designs. Appendix A shows the calculations required to choose the magnet size. These calculations were based on a Samarium cobalt magnet made by Indiana General and called Incor 16. A ceramic magnet structure which would use no cobalt was used in early evaluations. The magnetic structure utilizing a ceramic magnet weighed 348 grams or only 37 grams less than the whole final designed loudspeaker using Samarium cobalt.

The final dimensions of the magnet employed are 1.125 inches diameter and .110 inch thick. These were obtained by sawing in half a magnet of the same diameter and .250 inch thick.

There is a lot of concern over the scarcity of cobalt and, therefore, non-cobalt bearing magnets should be used where possible. As previously stated, a non-cobalt bearing magnet was much too heavy (and also too large) to be considered. The alternatives are the alnico magnets and Rare Earth cobalt magnets. Samarium cobalt magnets use less cobalt for the same performance and are similar in cost for the same performance, so they are therefore cobalt conservative. Figure 3 compares the B-H curves of the three types of magnets.

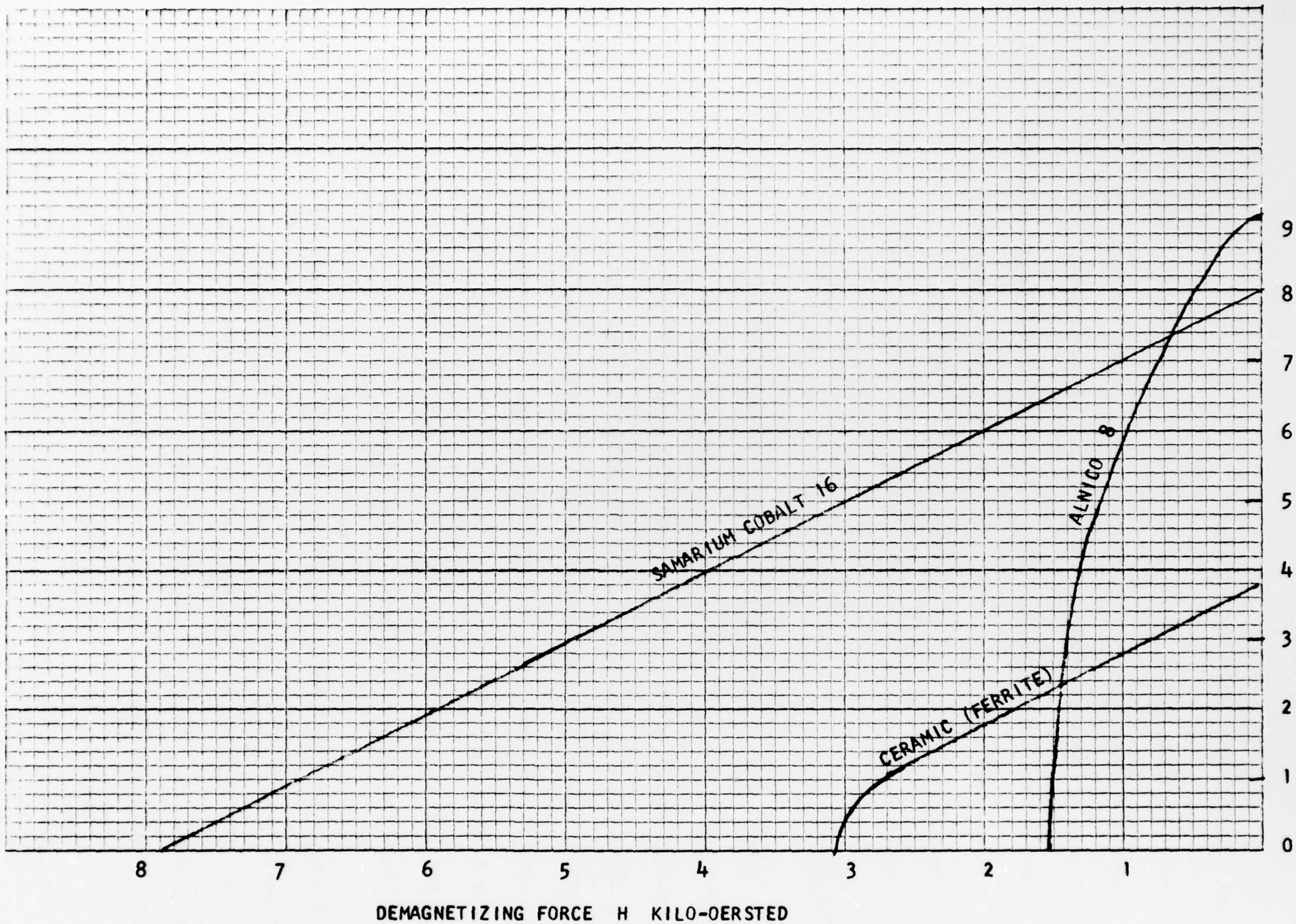
Specification for Incor 16 as follows:

Residual Induction B_r -------------------	8,100 Gauss
Coercive Force H_c -----------------------	7,900 Oersted
Intrinsic Coersive Force H_{ci} ------------	>16,000 Oersted
Normal Peak Energy Product $BdHd_{max}$ ------	16.0 Mega Gauss Oersted
Curie Temperature -----------------------	700^o C (Approx.)
Maximum Practical Operating Temperature -	250^o C
Density --------------------------------	.300 Lbs./In^3

<u>The Cone</u>

The requirements of the loudspeaker cone are many and varied. First and foremost, it should provide undistorted sound at the required level over the required frequency range. In addition to these acoustic requirements, it must keep the voice coil centered within the magnetic gap so as to not damage the coil. It must also be completely waterproof since the loudspeaker must pass a three foot immersion test. Beyond all these requirements is one that the cone must survive the Gunblast Test for percussive environments and near proximity to artillery.

To meet these requirements, cones were fabricated from several materials. The first attempts were made using treated paper cones. These cones are compliant and are good for a wide range of frequencies. Initial tests proved the material unable to withstand simulated gunblasts, however, and it was dropped in favor of Kapton, a high temperature thermosetting plastic. Kapton was used on the loudspeakers that Electro-Voice made for Skylab and, though difficult



COMPARISON OF MAGNET TYPES

FIG 3

to form, is very tough and will withstand high and low temperatures. The problem with Kapton is that it is not rigid enough to provide the sound required and stay below the maximum 5% total harmonic distortion. We experienced cone "break-up" at several frequencies that caused distortion of 7% to 10% at the 85 dB SPL level. The Skylab loudspeaker had a 10% distortion spec.

The next material tried was Mylar. Mylar is used for many microphone and earphone diaphragms. It is easy to form but proved to be too flexible to serve as a loudspeaker cone. A thickness that was stiff enough to keep distortion low was not compliant enough to reproduce low frequencies.

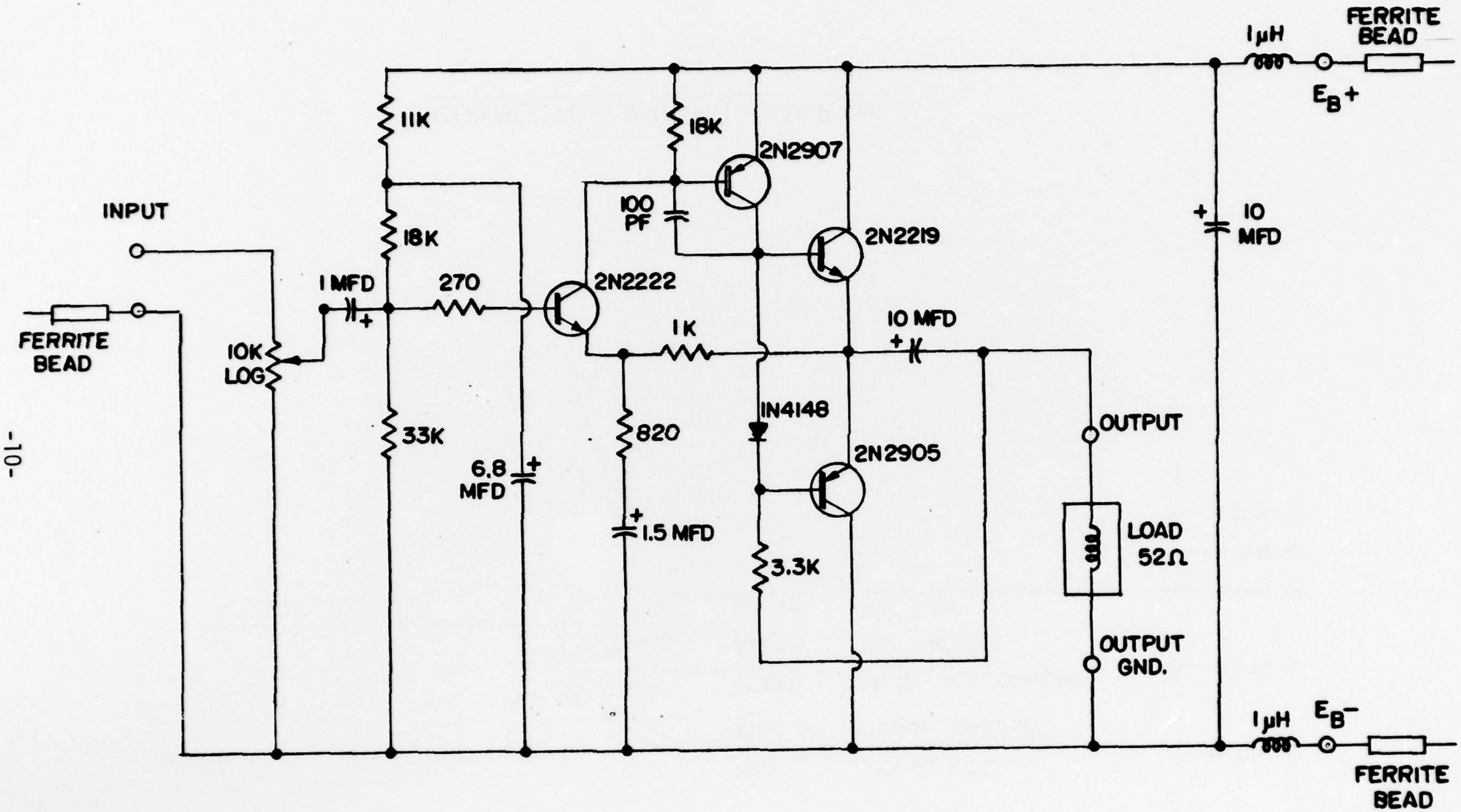
The last material tried and subsequently used was linen reinforced Phenolic. A cone made of this material and .005 inch thick proved to be the best combination of features desired. The cone is used without a spider because of the combined stiffness of the cone and the small acoustic cavity resulting from the case size restrictions. They caused too high a low frequency cutoff. Without the spider the speaker just fits within the envelope specified. With a spider the mechanical resonance is shifted up an additional 150 Hertz and the low frequency response reduced accordingly. The cone distorts somewhat at resonance (750 Hertz) when driven at full power with sine wave. Intelligibility is good, however. Distortion data for a typical unit is shown in Figure 6.

The Amplifier

Figure 4 shows the schematic diagram of the amplifier used in the development. This amplifier is designed to draw minimum current during periods when it is connected to the radio but no signal is provided to it. During these times the current draw is approximately 5 ma. In operation, the amplifier draws only 30 ma. while providing 200 milliwatts to the loudspeaker. This current draw is 30 ma. from both a 24 and a 12 volt source. The amplifier gain is adjusted to provide the 200 milliwatts with a two volt rms audio signal from the radio. Figure 5 shows the current draw and audio power delivered by the amplifier to the loudspeaker voice coil.

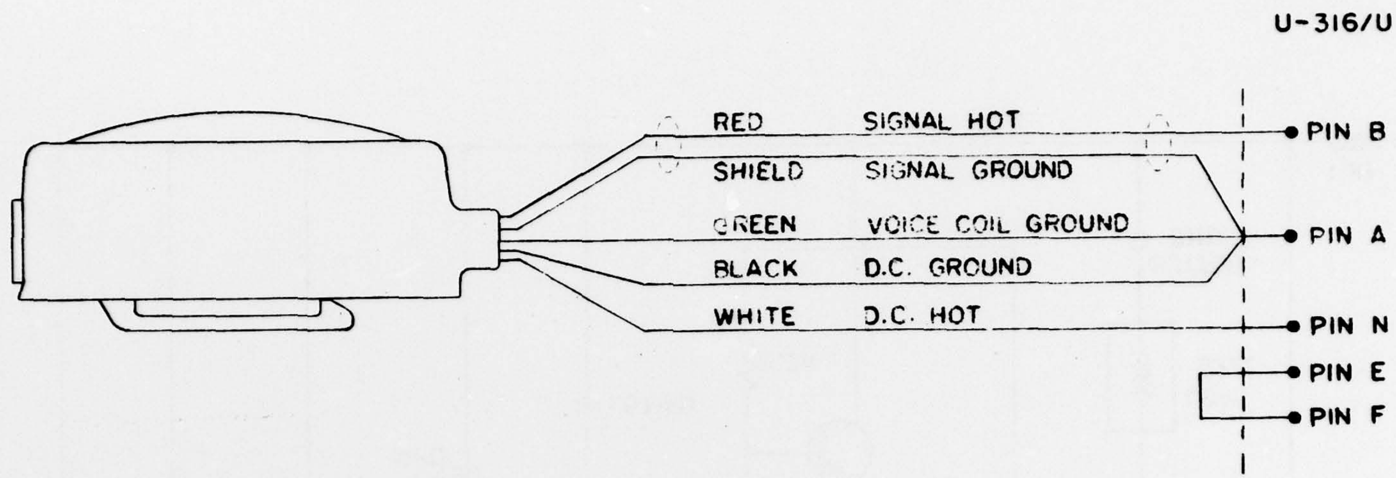
Amplifier Components

In light of the Nuclear Survivability requirement, research was performed to determine the best of various options for each component. First there appears to be no best choice for resistors, so standard carbon composition ones were chosen per Mil-R-39008 with 50% failure rate of 0.1%. Capacitor manufacturers advised the use of aluminum oxide electrolytics for extreme temperature environments and also high radiation environments. Studying transistor specifications revealed that "hardened" transistors survive best in low to moderate radiation areas such as around nuclear power plants, but transistors in general, however, do not



AUDIO POWER AMPLIFIER

FIG 4



CONNECTOR WIRING DIAGRAM

FIG. 7A

fare well in high radiation environments. We could not justify the 5 to 10 times increase in price for "hardened" transistors, so instead used JAN varieties. The volume control is a sealed unit utilizing a carbon composition element. It meets Mil-R-94 style RV6. An O-ring seal is employed in mounting.

The first amplifier design failed the EMI tests and some redesign took place. The one microhenry chokes and the ferrite beads are part of the redesign. The circuit shown in Figure 4 does meet the EMI requirements. Figure 4 shows how three conductors of the cable were used to keep a common ground between the DC and audio circuits. This was necessary to comply with the EMI requirement. The resistance of the tinsel leads allowed too much voltage drop between the DC and audio portions of the amplifier and caused line induced noise susceptibility. The greatest problem was in the audio region.

ENVIRONMENT TESTS

Altitude

Only a slight change in response was experienced at 15,000 feet simulated altitude when compared to ground level (800 feet). This is due to the mechanical stiffness of the cone surround being a major contributor to the overall mechanical stiffness. Had a cone with a very compliant surround been used, the natural resonance would have been a function of air density (i.e., altitude).

Low Temperature

The loudspeaker subjected was listened to while in a cold box at -50^{o} C as specified in DS-AF-0250A(A). No degradation in performance was observed. The response curve taken after returning to room temperature conditions confirmed that no damage was incurred.

High Temperature

The loudspeaker operated at 160^{o} F without apparent degradation in performance. We listened to a frequency sweep at this temperature and mentally compared it to a similar sweep at room temperature. The response curve taken at ambient temperature showed no degradation in performance. We further checked the gain of the amplifier at room temperature and at 160^{o} F and experienced less than 1 dB change.

Rain

The rain test went without a hitch. However, the speaker must be shaken to remove water held between the grille and the speaker cone by capillary action. One good shake was all that was necessary to obtain good sound. Response curve showed no change in performance as a result of the exposure to the rain.

Humidity

No change in performance was experienced as a result of exposure to humidity. The loudspeaker was operated during the last part of the test and sounded good. The problem would have been deterioration of adhesives and/or inadequate equalization during the hot and cold cycles.

Blast

As noted earlier, we initially failed the blast test. The speaker was then redesigned by adding retaining grilles in front of and behind the cone to restrict its motion. A smaller dome was used also since the larger one collapsed. Interim tests were performed using an air blast setup to simulate the gunblast test. The final test was performed using the SKN-864 setup at Astrocom Electronics. The response curve taken after the exposure to 30 blasts of 9.5 psi peak showed no degradation in performance.

All the above mentioned tests were performed on the same loudspeaker.

Salt Fog

A fresh loudspeaker was subjected to the Mil-Std-810C salt fog test. After 48 hours of the salt fog, the frequency response of the unit was made. No degradation was observed. Some corrosion of the cadmium plated screws was observed.

Immersion

A fresh loudspeaker (Unit 3) was subjected to the two hour immersion. Earlier attempts to pass the test were unsuccessful as water always got past the gasket on the rear cover. The response would not change because insufficient water would enter to alter the response. Believing that no water should enter the cavity, we worked out a method using a poured gasket of RTV silastic. This method keeps out all of the water. Dow Corning 3145 RTV was used. If the cover is removed, the gasket can also be removed and a new one poured. The test unit was subjected to the test and the subsequent response curve showed no degradation. There was no water in the cavity as checked by a shake and listen test. The unit could not be opened as a series of tests follow this one.

Dust

The above unit was sent to Elite Electronic Engineering in Chicago for the dust test. Upon return the speaker showed no degradation in performance.

Vibration

No degradation was experienced as a result of the vibration exposure.

Shock Drop

Early drop tests using machined cases were not successful which resulted in molding them from 10% glass filled polycarbonate. The stiffer cases have no problem. Not enough time was available to try the six foot drop onto asphalt covered concrete as used on the H-251 headset. We believe this drop test could probably be passed. After the prescribed drop onto two inch plywood backed by concrete the units were immersed again and showed no degradation after immersion.

Fungus

No fungus test was performed as the materials that were used are listed in Table 4-1, Group I Mil-Std-454. One exception is the cable which is our standard H-250 cable and which has been subjected to the fungus test on many occasions and always passes the test by not supporting fungus.

SUMMARY

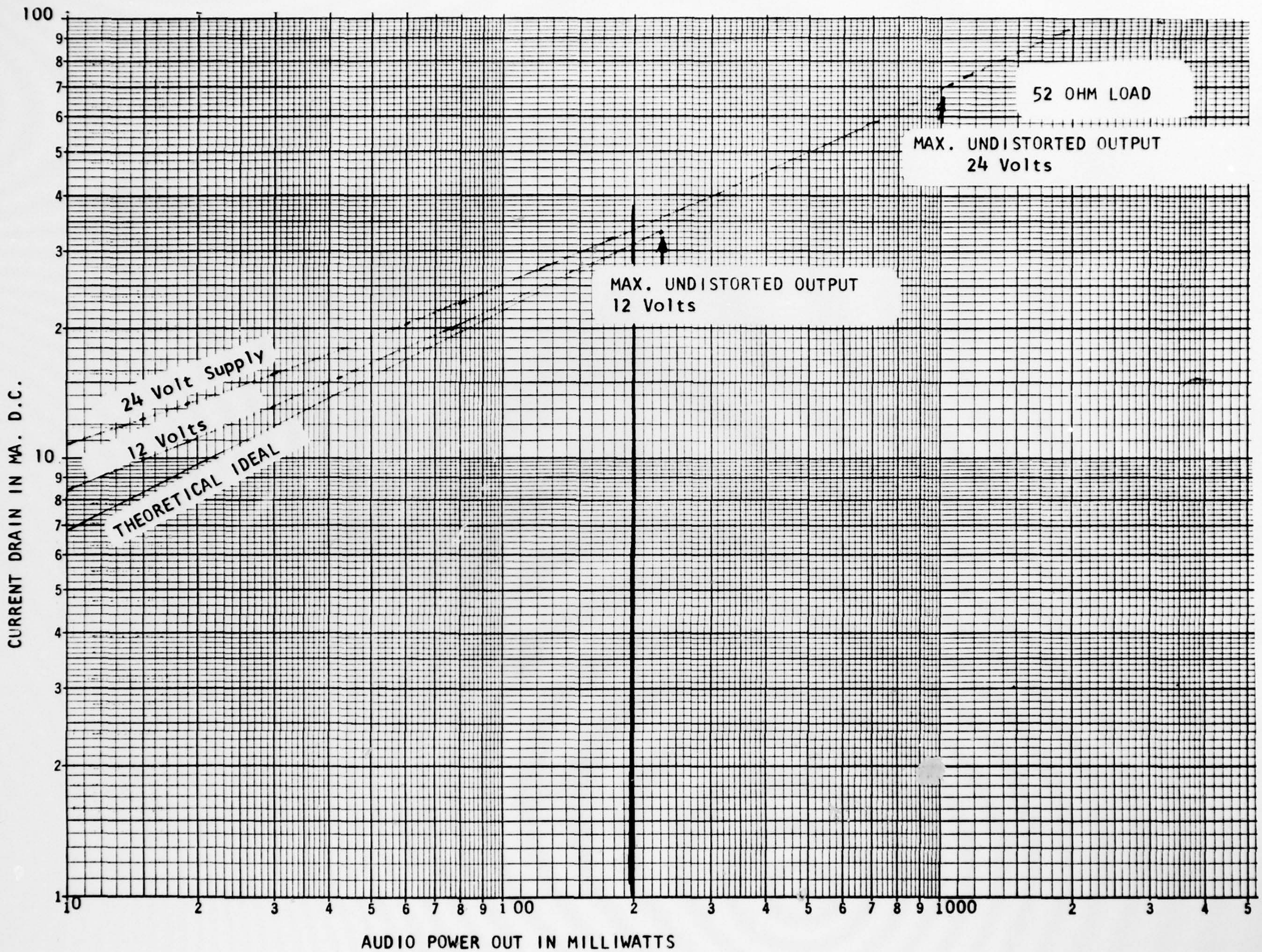
The loudspeaker resulting from the development effort is lightweight, small in size and delivers good intelligibility. The weight of the speaker, including cable and connector, is 385 grams which is 15% lighter than the maximum allowed. The size of the unit is 3.86 inches diameter and 1.56 inches thick which results in a slight reduction in cross sectional area over the original specification of 3.5 inches by 3.5 inches by one inch. However, the volume is greater because of the 50% greater thickness.

A typical response curve is shown in Figure 6. The curve does fit the LS-445 response, but barely. The LS-445 uses a similar cone but the acoustic cavity provided for the cone is several times as large as that available in the small case of the Lightweight Portable Loudspeaker. The smaller cavity provides a greater stiffness resulting in less low frequency response.

The output level between 500 Hertz and 2000 Hertz falls below 85 dB SPL in places since the low frequencies are rolled off as explained previously. The peak at 750 Hertz is the resonance of the speaker cone stiffness and the cavity stiffness with the cone and voice coil mass. At this point the voice coil looks the most reactive (inductive) and wants to resonate with the coupling capacitor in the amplifier. Space limitation prevents the use of a larger capacitor and a smaller capacitor would further roll off the low frequencies.

PHYSICAL SPECIFICATIONS

Cone Diameter	3.0 Inches
Coil Diameter	.75 Inches
Coil Length	.180 Inches
Front Plate Thickness	.150 Inches
Magnet Thickness	.110 Inches
Magnet Diameter	1.125 Inches
Coil Impedance	50 ± 5 Ohms
Coil Wire Size	#42 AWG 160 Turns
Case Material	Polycarbonate 10% Glass Filled
Case Dimensions	3.86 In. Dia. x 1.56 In. Thick



52 OHM LOAD
MAX. UNDISTORTED OUTPUT
24 Volts
MAX. UNDISTORTED OUTPUT
12 Volts
24 Volt Supply
12 Volts
THEORETICAL IDEAL
CURRENT DRAIN IN MA. D.C.
AUDIO POWER OUT IN MILLIWATTS

Fig 5

APPENDIX A

First a calculation of acoustic output possible if amplifier delivery 200 milliwatts of power to voice coil

$$I = \frac{P^2}{PC}$$ Where P is the density of air and C is the velocity of sound in air. PC = 42.7

At a distance of three feet from the loudspeaker the sphere of sound emitted would have the area

$$S = \pi d^2 = \pi(3 \times 12 \times 2.54)^2 \ \mathrm{cm}^2$$

$$= 26267.7 \ \mathrm{cm}^2$$

For 1/2% efficiency typical of direct radiators we have

$$I = \frac{.005\ W \times 10^7}{A} \qquad W = \text{Amp Power Out}$$

At three feet and 200 milliwatts

$$I = \frac{.005(.2)10^7}{S} = .380 \ \text{erg/sec.}$$

$$\frac{P^2}{42.7} = .380 \qquad P = 4.028 \ \text{dynes/cm}^2$$

$$P = 20 \log \frac{4.028}{.0002} = 86 \ \text{dB SPL}$$

APPENDIX B

Magnet Size Determination

Experimentally determined flux needed for correct level to be 18,000 maxwells or 7,900 gauss in a structure with a .750 diameter polepiece and a .150 thick faceplate.

MMF $\quad \mathcal{F} = \dfrac{\phi \ell}{A}$ $\quad$ Where ϕ is in maxwells, ℓ is gap width in cm.

A in cross sectional area is cm^2

$$\mathcal{F} = \frac{(18{,}000)(.028 \text{ in} \times 2.54 \frac{cm}{in}}{.150 \times .750 \times \pi(6.45 \frac{cm^2}{in^2})} = 561 \text{ Gilberts}$$

With 25% loss we have 701 Gilberts.

Using magnetic material having an energy product of 16 megogaussoersteds (Samarium cobalt) operation at 4K gauss for maximum energy product, we have 4 oersteds.

$$1 \text{ Oersted} = \frac{1 \text{ Gilbert}}{cm}$$

$$\frac{701 \text{ Gilberts}}{4000 \frac{\text{Gilberts}}{cm}} = .175 \text{ cm} = .069 \text{ in. thick}$$

For area we have

$$\frac{18{,}000 \text{ Maxwells}}{4000 \frac{\text{Maxwells}}{cm^2}} = 4.5 \text{ cm}^2 = .69 \text{ in}^2$$

if we assume 25% leakage = .86 in^2 = 1.04 in diameter

A magnet 1.125 in. diameter and .110 in. thick was chosen. .069 in. thick was considered too fragile.

Electro-Voice

a gulton company

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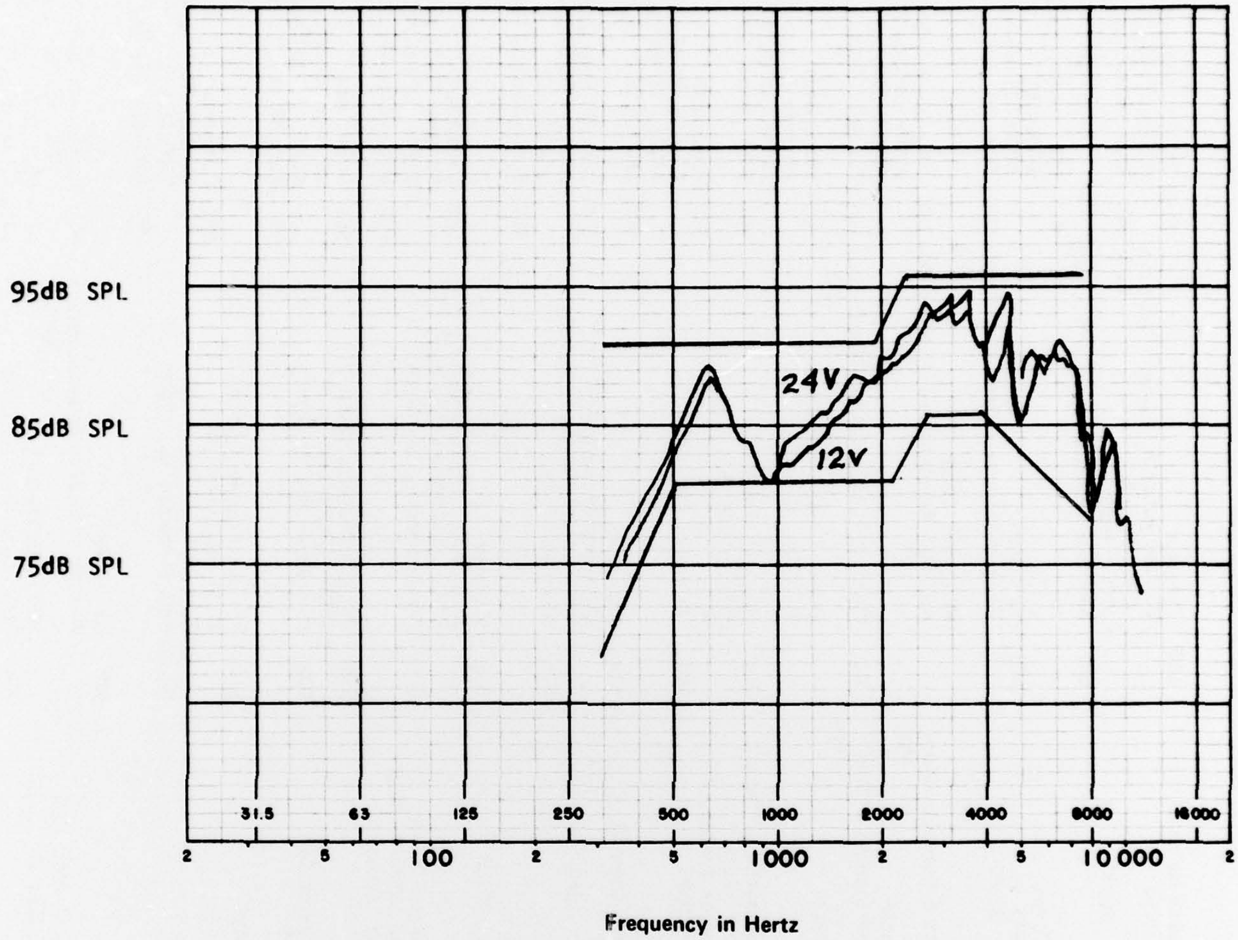

Frequency (Hz)	400	1000	2000	4000
Distortion(%)	3.5	2.0	1.0	0.7

Fig 6

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